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THE EFFECT OF A STEM TEACHING INTERVENTION ON THE DEVELOPMENT OF PRACTICES FOR PLANNING INVESTIGATIONS

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Abstract:
The purpose of the present paper is to investigate the contribution of a STEM teaching intervention to the development of practices for planning investigations in high-school students. STEM instructional material was developed based on the constructivist approach to learning with the use of science and engineering practices. The instructional material included a weather station consisting of a microcontroller with humidity, temperature, pressure, light intensity and raindrop sensors. The instructional material developed was implemented in 38 high-school students and the data was collected through a questionnaire completed by the students before and after the end of the teaching intervention. The research data included students' answers to the questionnaires. The data analysis showed that the students are able to develop and use practices for planning investigations through the implementation of the instructional material that was constructed.

Keywords: STEM instructional material, planning investigations, weather station

1. Introduction

The tendency towards integration among different scientific fields has not left education unaffected. There is an ever-increasing interest in connecting the curricula to the instruction of the various disciplines (English, 2016; Johnson, Peters-Burton & Moore, 2015; Kurt & Pehlivan, 2013). It is alleged that the current curricula are particularly restricted and fail to teach the students how to learn in a world where scientific, technological and social issues are entangled with each other and that there is necessity for developing integrated curricula including Science, Technology, Engineering and Mathematics (STEM), as everyday life cannot be divided into separate insulated fields (Czerniak & Johnson, 2014; Honey, Pearson & Schweingruber, 2014).

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According to the new science education framework proposed by the US National Research Council, students comprehend ideas and concepts through their engagement in science and engineering practices (NRC, 2012). Consequently, students should develop and use such practices. However, the research studying the contribution of teaching interventions to the development of practices in students is particularly limited (Arnold, Kremer & Mayer, 2014).

The present paper belongs to the research field that studies the effect of STEM teaching interventions on science and engineering practices developed by the students. In particular, it is focused on studying the effect of a STEM teaching intervention about weather on the development of practices for planning investigations.

2. Theoretical Framework

2.1 Learning Objects

The term "STEM education" refers to teaching and learning in the fields of Science, Technology, Engineering and Mathematics (Breiner, Harkness, Johnson & Koehler, 2012; Bybee, 2010; Stohlmann, Moore & Roehrig, 2012). It includes educational activities based on the above fields and may extend to the entire age range of education (Gonzalez & Kuenzi, 2012). Especially nowadays, planning and implementing STEM integrated curricula is proposed so that today's students and future citizens can become capable of exploiting multidisciplinary knowledge and skills in order to be able to understand and deal with complex issues (Ríordáin, Johnston & Walshe, 2016).

Furthermore, according to the constructivist approach to learning, the student constructs knowledge actively through cognitive, social and cultural processes instead of receiving it passively (Forbes et al., 2014). One of the main constructivist points is that students hold conceptions of the natural world that have been formed from their experience (Driver et al., 1985). The mental and practical work related to processing and revising students' conceptions is based on students' engagement in science and engineering practices (NRC, 2012). The term "science and engineering practices" refers to the main practices used by scientists for the construction of models and theories (NGSS Lead States, 2013). Science and Engineering practices are as follows: (a) asking questions and defining problems, (b) developing and using models, (c) planning and carrying out investigations, (d) analyzing and interpreting data, (e) using mathematical and computational thinking, (f) constructing explanations and designing solutions, (g) engaging in argument from evidence, (h) obtaining, evaluating, and communicating information.

It is claimed that students' active engagement in practices could help them understand the process of developing scientific knowledge, construct basic ideas and concepts, attract their curiosity and interest as well as encourage them to conduct further research (NRC, 2012). One of the practices of science and engineering concerns planning and carrying out investigations. Through this practice, the students are intended to identify and control the variables (independent variable, dependent variable and control variables), and invent and describe the experimental process they will follow in order to answer the questions (Duschl & Bybee, 2014).

3. Literature Review

The research that has been conducted and focuses on students' planning investigations showed that the students find difficulty in planning investigations. In particular, they find difficulty in identifying variables (independent variable, dependent variable and control variables) as well as in describing the experimental process (Chen & Klahr, 1999; Duggan & Gott, 2000; Khishfe & Lederman, 2006). However, while students' practices for planning investigations have been studied, there is limited research studying the contribution of teaching interventions to these students' practices (Arnold et al., 2014; Chen & Klahr, 1999; Klahr & Nigam, 2004; Kyriazi & Constantinou, 2005).

Furthermore, the attempts to improve mathematics and science education have focused more on the disciplines themselves (mathematics and science) rather than on whether and how these fields can be connected with each other in order to improve learning outcomes. The research on the effect of the implementation of STEM curricula on students' performance is limited. The results show that integrated curricula can contribute to learning the concepts of the individual fields and that the learning outcomes depend on the nature of integration, the method followed for evaluating the learning outcomes and the initial knowledge of students (Nadelson & Seifert, 2017; Thibaut et al., 2018). However, when it comes to the issue of whether the STEM instructional material could become part of the solution to the problem related to the efficiency of teaching, there are more questions than answers. It is established that there is very little data connecting STEM instructional material to learning outcomes (Honey et al., 2014). In addition, there is no research studying the effect of STEM teaching interventions on the development of science and engineering practices in students, which reveals the need for conducting further research.

The originality of the present paper lies in the fact that it studies the contribution of a STEM teaching intervention about weather to the development of practices for planning investigations, which is an issue lacking research data.

4. Purpose and Research Questions

The purpose of the present paper is to study the effects of a STEM teaching intervention about weather on the development of practices for planning investigations in high-school students.

In particular, the present paper aims to answer the following research questions:

a) What is the contribution of STEM teaching intervention about weather to high-school students' practices for identifying the dependent variable, the independent variable and the control variables?

b) What is the contribution of STEM teaching intervention about weather to students' practice for describing an experimental process that should be followed?

5. Methodology

5.1 Research Process Phases and Participants

At first, the instructional material about weather and a questionnaire examining students' practice for planning investigations were developed (pilot study). Then the instructional material was implemented in the students and the questionnaires were completed by them before and after the teaching intervention. Thirty-eight high-school students participated in the research.

5.2 STEM Instructional Material and Teaching Process

The weather station involved in the present research paper was based on a weather station with NodeMCU microcontroller. The weather station consists of hardware and software.

The hardware includes the NodeMCU microcontroller unit, the humidity-temperature sensor, the lightning sensor, the barometric sensor and the raindrop sensor. Furthermore, the hardware includes connection wires, communication wires (USB→micro USB) between the microcontroller and the computer, the breadboard, resistances, diodes and the computer.

The weather station software includes the microcontroller's programming environment, i.e. ARDUINO IDE, the IoT environment of the server ThingSpeak, where the data will be registered and which will additionally provide charts, visualization through visual instruments as well as lots of possibilities for data statistical processing. Finally, it includes an IoT Cayenne automation platform, which is accessed through the Cloud from a computer and through a smartphone application from Google Play. In addition, the construction of the station required the Fritzing software for the design of electronic circuits, while the Tinkercad software for 3D design and the creation of 3D files for printing was used for designing the external protective frame of the station.

The instructional material was designed on the basis of the constructivist approach to learning with the use of science and engineering practices. The development of the instructional material involved the 5E instructional model of Bybee, Taylor, Gardner, Van Scotter, Powell, Westbrook and Landes (2006), which includes the following five phases.

a) Engagement: This phase intended to attract students' interest, reveal their original conceptions (about weather, climate, possibilities and configuration of microcontrollers), make them realize the disagreements among them and formulate research questions. In particular, the students at first worked individually and recorded their predictions and justifications of problems they were presented with. Then, they discussed with the schoolmates of their group and compared their answers. Finally, the students held a discussion at class level under the coordination of the teacher and formulated the research questions.

b) Exploration: This phase aimed at students' planning and carrying out investigations with the future aim of creating a cognitive destabilization of their initial conceptions and constructing new conceptions in the direction of school knowledge. In particular, the students planned and carried out investigations with the help of appropriate questions included in their worksheets in order to answer the research questions they had been given. After making assumptions, they identified the variables involved in the investigations, controlled the variables (by identifying the independent and the dependent variable as well as the control variables), described the experimental process they would follow, collected the data through the weather station, and entered it in tables.
c) Explanation: In this phase, the students processed the tables with the data, extracted conclusions from them and compared them with their initial predictions. In this phase, the students were intended to construct documented explanations (explanations based on evidence they had collected).
d) Elaboration: This phase aimed at implementing the knowledge of new problems acquired by the students and providing the students with feedback. In particular, the students processed problems different from those they had initially negotiated so that it could be examined to what extent they could activate the new knowledge in new problems. During the implementation of these activities, the students discussed their answers with their schoolmates by comparing and contrasting their ideas.
e) Evaluation: In the fifth phase, the students were asked to compare their initial with their new answers as well as to identify similarities and differences between them.

5.3 Data Collection and Analysis

The data collection tool was the questionnaire, which included four questions (Table 1). An introductory text (problem) preceded the questions. The introductory text informed the students that they should examine whether the number of batteries included in an electromagnet affects its tractive force. Question 1 asked the students to report the factor that should be changed in the specific research (independent variable). Question 2 asked the students to report the factors that should remain unchanged (control variables). Question 3 asked the students to choose the factor that should be measured in the specific research (dependent variable). Question 4 asked the students to describe in detail the experimental process that corresponds to the specific research and should be carried out.

Table 1: Questions and Respective Investigation Planning Practices.

Questions	Investigation Planning Practices
1	Identifying the independent variable
2	Identifying the control variables
3	Identifying the dependent variable
4	Describing the experimental process

The research data included students' answers to the questionnaires before and after the teaching intervention. The analysis of students' answers was based on the frameworks of analysis by Arnold et al. (2014). These frameworks classify students' answers into four levels. Table 2 presents the framework of analysis for identifying the independent variable, the control variables and the dependent variable as well as for describing the experimental process.

Table 2: Framework of Analysis of Students' Answers with regard to Planning Investigations: Levels and Description

Dimensions	Levels	Description
Identifying the Independent Variable	0	The student does not suggest the independent variable or reports more than one independent variables.
	1	The student suggests an irrelevant independent variable or suggests a relevant independent variable, though it is not clarified whether it is a quantitative or a qualitative factor.
	2	The student presents the independent variable in qualitative terms.
	3	The student presents the independent variable in quantitative terms.
Identifying the Control Variables	0	The student does not suggest any control variables.
	1	The student vaguely suggests some variables or suggests irrelevant control variables.
	2	The student suggests one or two relevant control variables.
	3	The student suggests more than two relevant control variables.
Identifying the Dependent Variable	0	The student does not suggest any dependent variables.
	1	The student suggests an irrelevant dependent variable or suggests a relevant dependent variable, though it is not clarified whether it is a quantitative or a qualitative factor.
	2	The student presents a relevant dependent variable in qualitative terms.
	3	The student presents a relevant dependent variable in quantitative terms.
Describing the Experimental Process	0	The student does not suggest any experimental processes.
	1	The student suggests an irrelevant experimental process.
	2	The student suggests an experimental process and explicitly refers to 1 to 3 of the following items: independent variable, control variables, dependent variable and measuring instrument.
	3	The student suggests an experimental process and explicitly refers to the independent variable, the control variables, the dependent variable and the measuring instrument.

6. Results

6.1 Identifying the Independent Variable

Before the teaching intervention, most students' answers to the question asking the students to suggest the independent variable were included in levels 1 (42.10%) and 0 (21.05%), while answers included in level 3 were limited (26.3%) (Table 3). This shows that most students did not suggest any independent variable or suggested irrelevant independent variable. In contrast, after the teaching intervention, most students' answers to this question were included in level 3 (52.63%), which means that most students suggested the appropriate independent variable.

What is more, there is a statistically significant difference between the levels of students' answers before (Mdn=1.00) and after (Mdn=3.00) the teaching intervention, with Z=-2.045, p=0.041. As a result, with regard to identifying and recording the independent variable, it emerged that the levels of students' answers after the teaching intervention were statistically significantly improved as compared to the respective levels before the teaching intervention.

Table 3: Levels of Students' Answers to Question 1: Frequencies and Percentages.

Levels	**Pre-test**		**Post-test**	
	f	**%**	**f**	**%**
Level 0	8	21.05	6	15.78
Level 1	16	42.10	10	26.31
Level 2	4	10.52	2	5.26
Level 3	10	26.31	20	52.63

6.2 Identifying the Control Variables

Before the teaching intervention, most students' answers to the question asking the students to suggest the control variables were included in levels 0 (31.57%) and 1 (36.84%), while answers included in level 3 were limited (15.78%) (Table 4). This shows that most students either did not suggest any control variables or suggested irrelevant control variables. In contrast, after the teaching intervention, students' answers included in levels 2 and 3 increased (21.05% and 36.84%, respectively). This shows that most students suggested one or two appropriate variables or more than two appropriate control variables.

What is more, there is a significant difference between the levels of students' answers before (Mdn=1.00) and after (Mdn=3.00) the teaching intervention, with Z=-2.562, p=0.010. As a result, with regard to identifying and recording control variables, it emerged that the levels of students' answers after the teaching intervention were statistically significantly improved as compared to the respective levels before the teaching intervention.

Table 4: Levels of Students' Answers to Question 2: Frequencies and Percentages.

Levels	Pre-test		Post-test	
	f	%	f	%
Level 0	12	31.57	10	26.31
Level 1	14	36.84	6	15.78
Level 2	6	15.78	8	21.05
Level 3	6	15.78	14	36.84

6.3 Identifying the Dependent Variable

Before the teaching intervention, most students' answers to the question asking the students to suggest the dependent variable were included in levels 0 (26.31%) and 1 (36.84%), while answers included in level 3 were limited (21.05%) (Table 5). This shows that most students did not suggest any dependent variable but they suggested an irrelevant dependent variable or a relevant dependent variable, though it was not clarified whether it was a quantitative or a qualitative factor. After the teaching intervention, most students' answers continued being included in levels 0 (10.52%) and 1 (47.36%), while students' answers included in level 3 increased (26.31%).

However, there is no statistically significant difference between the levels of students' answers before (Mdn=1.00) and after (Mdn=1.00) the teaching intervention, with Z=-1.261, p=0.207.

Table 5: Levels of Students' Answers to Question 3: Frequencies and Percentages.

Levels	Pre-test		Post-test	
	f	%	f	%
Level 0	10	26.31	4	10.52
Level 1	14	36.84	18	47.36
Level 2	6	15.72	6	15.78
Level 3	8	21.05	10	26.31

6.4 Describing the Experimental Process

Before the teaching intervention, most students' answers to the question asking the students to suggest the experimental process were included in levels 0 (47.36%) and 1 (31.57%), while answers included in level 3 were particularly limited (5.26%) (Table 6). This shows that most students did not suggest any experimental processes or they suggested an irrelevant experimental process.

Table 6: Levels of Students' Answers to Question 4: Frequencies and Percentages.

Levels	Pre-test		Post-test	
	f	%	f	%
Level 0	18	47.36	10	26.31
Level 1	12	31.57	12	31.57
Level 2	6	15.78	4	10.52
Level 3	2	5.26	12	31.75

In contrast, after the teaching intervention, students' answers included in level 3 increased (31.75%). This shows that several students suggested an experimental process and explicitly referred to the independent variable, the control variables, the dependent variable and the measuring instrument.

What is more, there is a significant difference between the levels of students' answers before (Mdn=1.00) and after (Mdn=1.00) the teaching intervention, with Z=-2.707, p=0.007. As a result, with regard to describing the experimental process, it emerged that the levels of students' answers after the teaching intervention were statistically significantly improved as compared to the respective levels before the teaching intervention.

7. Discussions and Conclusion

The findings of the present paper show that the students can improve the practice for planning investigations through the instructional material that was developed and implemented. After the completion of the teaching intervention, the number of students that were able to identify the independent variable, the control variables and the dependent variable was increased, as it happened with the number of students that were able to describe the experimental process, while before the teaching intervention, only a few students had been familiar with these dimensions of the practice for planning an investigation. Furthermore, the implementation of the instructional material in the students showed a significant difference among the levels of students' answers in three out of the four questions they were asked before and after the teaching intervention.

Students' improvement could be attributed to the STEM instructional material that was developed and implemented. Through its activities, the instructional material offered the students the possibility of planning and carrying out investigations. These activities provided the students with the opportunity to formulate research questions, make assumptions, identify during the research process the independent variable, the control variables and the dependent variable as well as to describe the experimental process that should be followed so that a research question could be answered. It has become clear that these activities can contribute to the improvement of students' practices for designing investigations (Roth & Roychoudhury, 1993). The difficulty all the students had in developing such practices could be attributed to the fact that they are not familiar with these practices because schools mainly follow the traditional science teaching approach, according to which the teacher acts as the possessor and transmitter of knowledge, which is introduced to the students through questions and answers, while the students are not engaged in investigation processes (Antoniadou & Skoumios, 2013).

Thirty-eight high-school students participated in the research and, as a result, the research findings are subject to the restrictions of the sample. Moreover, the research was conducted only with questionnaires. The additional use of the interview would allow further investigation into the process for developing the practice for planning investigations.

The present paper was focused on investigating the contribution of STEM instructional material about weather to the development of a science practice for planning investigations. The instructional material also intended to familiarize the students with concepts of Science, Technology, Engineering and Mathematics. It is therefore suggested that the contribution of this instructional material to learning microcontroller programming, assembling sensors and microcontrollers as well as to students' conceptions of the weather, the climate and possibilities be studied. In addition, further research is required so that the contribution of STEM teaching interventions to the development of other science practices, apart from planning investigations (suggestively: developing and using models, constructing explanations and engaging in arguments), both in primary and secondary education, can be studied.

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